RUTTING EVALUATION OF ASPHALT PAVEMENTS USING FULL-SCALE ACCELERATED LOAD AND LABORATORY PERFORMANCE TESTS

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ABSTRACT

This paper addresses the rutting behavior of asphalt concrete pavements under high temperature loading conditions. Included are: 1) a brief summary of the results of heavy vehicle simulator (HVS) tests on two different asphalt mixes for a range in tire types, including a Goodrich Aircraft tire operating at a tire pressure of 1040 kPa (150 psi); and 2) the results of rutting tests on a mix containing a modified binder subjected to dual-radial truck tires. The data illustrate how the effects of different tire types and a range in loading conditions on permanent deformation in asphalt mixes can be evaluated relatively quickly using full-scale accelerated pavement testing.

The use of the repeated simple shear test at constant height (RSST-CH) for mix rutting evaluation is briefly described. Relationships between RSST-CH results and results of the HVS tests are presented. Data comparing predicted rutting using the RSST-CH test results and measured rutting in the HVS tests are also presented.

Results of the above analyses suggest that it is possible to use the RSST-CH for the establishment of mix design criteria for airfield taxiways. An example is presented using this approach for developing mix design criteria for taxiways subjected to Boeing 747-400 fully loaded aircraft.

The paper emphasizes the importance of combining the results of laboratory performance tests, suitable analytically-based methodology, and the results of full-scale accelerated pavement tests (in this case using the HVS). This approach permits the development of improved capabilities for the analysis and design of asphalt mixes and pavement structures to accommodate changed loading conditions and to effectively utilize new materials.

INTRODUCTION

The Caltrans Accelerated Pavement Testing (CAL/APT) Program, a research and development activity currently operating through the Partnered Pavement Research Center at the University of California, Berkeley, is a joint effort between Caltrans (the California Department of Transportation), the University of California at Berkeley (UCB), the Division of Roads and Transport Technology of the Council of Scientific and Industrial Research (CSIR) of the Republic of South Africa, and Dynatest Consulting, Inc. of Ventura, California.

The program utilizes two Heavy Vehicle Simulators (HVS) developed in South Africa. One of the HVS units is used to test full-scale pavements in a controlled environment at the UCB Richmond Field Station (RFS) while the other is utilized for testing in-service pavements. An extensive laboratory testing program involving the laboratories of UCB, Caltrans and CSIR complements the full-scale accelerated loading testing. Figure 1 illustrates a simplified framework within which the program operates.

This paper focuses on studies associated with the rutting behavior of asphalt concrete pavements under high temperature loading conditions. These studies have covered an approximately four year period and have involved combining the results of laboratory performance tests, suitable analytically-based methodology, the results of full-scale accelerated performance tests using the HVS, and an evaluation of the in-service performance of taxiways at the San Francisco International Airport subjected to slow moving Boeing 747-400 traffic.

It is the intent of this paper to illustrate how such a combined approach permits the development of improved capabilities for the analysis and design of asphalt mixes to accommodate changed loading and to effectively utilize new materials.

The paper includes: 1) a brief description of the HVS units and the use of the HVS to establish tire pressure distributions for a number of tire types using a 3-D sensor developed by CSIR (*2*); 2) results of a comparative study of the effects of tire type on mix rutting at elevated temperatures; 3) the use of the repeated simple shear test at constant height (RSST-CH) for mix rutting analysis/design and for rutting prediction; and 4) the use of the RSST-CH to establish mix design criteria for taxiways subjected to heavy aircraft loading.

HEAVY VEHICLE SIMULATOR

Figure 2 contains a diagram and specifications for the HVS Mark III developed by the CSIR. Two of these units were purchased by Caltrans in 1994; both units have been in almost continuous operation since spring of 1995[1] (*1*).

Wheel loads of up to 200 kN (45,000 lb.) are applied on a half axle using dual, standard-size truck tires or a single aircraft tire. The loads move in either a bi-directional (for fatigue evaluation) or a unidirectional (for permanent deformation evaluation) mode at speeds up to 10 km/h. (6.2 MPH). At this rate, up to 18,000 load repetitions can be applied per day in the bi-directional mode. Longitudinal wheel travel is 8.0 m (26.2 ft.) and lateral travel is programmable over 1.5 m (4.9 ft.).

Pavement instrumentation and evaluation equipment routinely used includes: multi-depth deflectometers (MDD), laser profilometer, road surface deflectometer (RSD), crack activity meter (CAM), thermocouples, photographic surface crack monitoring equipment, and a nuclear density gauge.

These data are useful both for permanent deformation (rutting) estimation and for evaluation of fatigue cracking. For example, for permanent deformation analyses, 3-D finite element simulations using distributions like those shown in Figure 3 indicated that the deformation experienced in the AC layer depends strongly on the layer's resistance to shape distortion and to a lesser degree on resistance to volume change (*3*). In addition, the simulations indicated that the majority of the deformation in the AC layer occurs in the 75 mm (3 in.) immediately below the tire-pavement contact area. For highway loading conditions, this finding is corroborated by field observations in the HVS rutting studies, in the WesTrack accelerated pavement test (*4*), and by observations of mixes in existing pavements [e.g., Reference (*5*)].

[1] During the period Nov. 2000 –February 2001 and July – September 2001, the HVS units were refurbished with new electrical and hydraulic systems and upgraded with computer controls for the loading system.

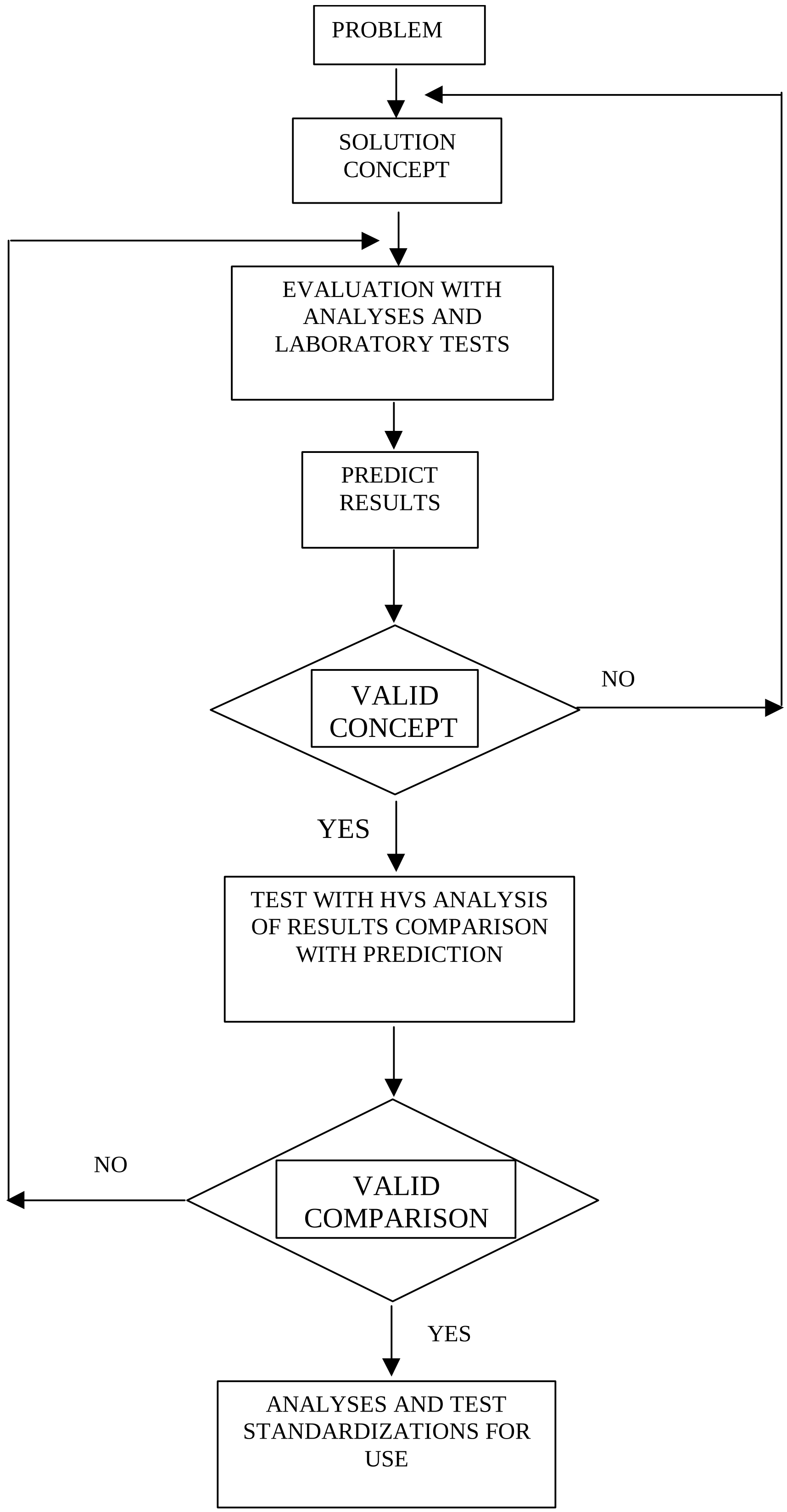


Figure 1. CAL/APT Framework

RUTTING EVALUATIONS AT HIGH PAVEMENT TEMPERATURES

During an approximately 5 month period (May to September, 1997) a total of 10 HVS tests were performed to: 1) evaluate the relative rutting performance of two mixes used as overlays on pavements for which Caltrans has responsibility, the one containing a dense-graded aggregate with an AR-4000 asphalt cement (DGAC) and the other a gap-graded aggregate containing a crumb rubber modified asphalt (ARHM-GG or RAC-G); and 2) to assess the relative effects of different tire types on mix rutting.(*6*)

Overall weight:		59,646 kg (131,500 lbs.)
Load weight of the test wheel		20-100 kN (4,500-22,500 lbs.) with truck tire
		20-200 kN (4,500-45,000 lbs.) with aircraft tire
Tire Pressure		690 kPa (truck tires); 1040 kPa (aircraft tires)
Dimensions of tested area of pavement		1.5 m × 8 m (4.9 ft × 26.2 ft) maximum
Velocity of the test wheel		10 km/h (6.2 mph) maximum
Maximum trafficking rate		1000 repetitions/hr
Average trafficking rate		750 repetitions/hr
Average daily repetitions		16,000 (including daily maintenance)
Engines:	Hydraulic plant	10-cylinder diesel
	Electrical plant/hydraulic control	6-cylinder diesel
Dimensions:	Length	22.56 m (74 ft
	Width, overall	3.73 m (12 ft)
	Height	3.7 m (12 ft)
	Wheel base	16.7m (55 ft)
Number of axles		3 (1 in rear, 2 in front)

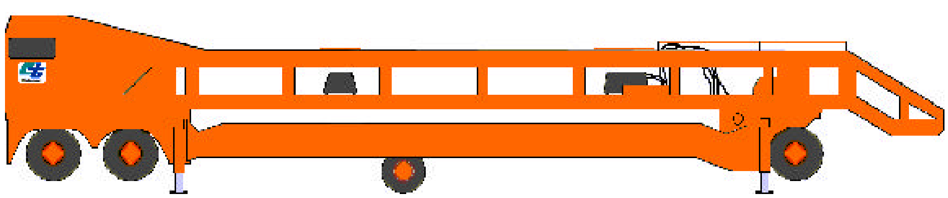
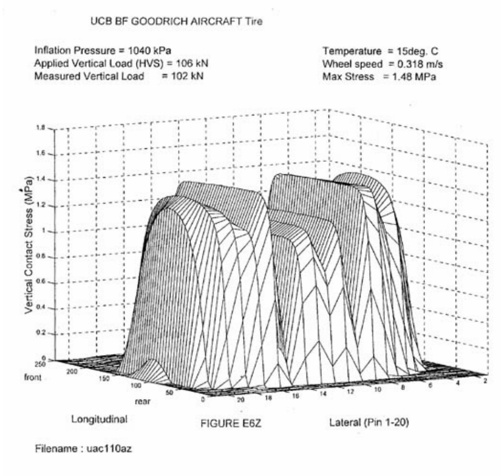
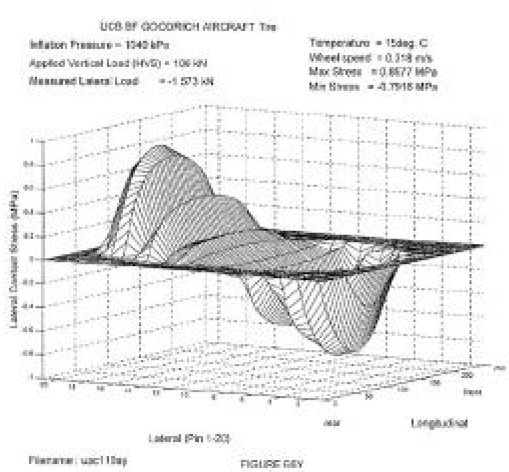


Figure 2. Diagram and specification of HVS

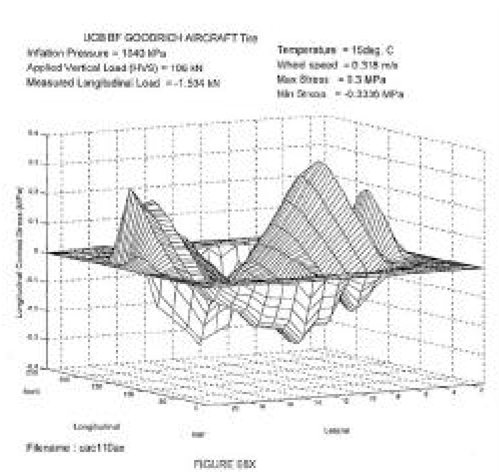


A. Vertical Contact Stress



B. Lateral Contact Stress

Figure 3. Stress distributions, Goodrich aircraft tire; inflation pressure = 1040 kPa (150 psi); vertical load = 106 kN (23,900 lb).



C. Longitudinal Contact Stress

Figure 3 (cont.). Stress distributions, Goodrich aircraft tire; inflation pressure = 1040 kPa (150 psi); vertical load = 106 kN (23,900 lb)

Table 1 lists the mixes tested as well as reference to the specific tires associated with the ten tests. For all of the tests, the HVS load carriage was operated in the channelized mode, i.e., without wander, and the loading was applied in only one direction.[2]

[2] When the HVS operates in unidirectional mode, the HVS wheel travels the 8-m long section loaded in one direction. It rolls up a short ramp at the end of the section and is locked in a position in which the wheel is not in contact with the pavement. The wheel is then pulled back to the beginning of the section where it is placed in contact with the pavement for the next cycle.

Table 1. Experiment Matrix for The HVS Rutting Test Series

Section	Mix type	Wheel type	Loading Condition	Speed (Standard Deviation)	Temp°C @ 50 mm
504RF	Original DGAC (137 mm)	wide base single[a]	40 kN, 110 psi	7.69 km/h (0.35)	50
505RF	Overlay DGAC (75 mm)	bias-ply dual[b]	40 kN, 90 psi	7.74 km/h (0.54)	50
506RF	Overlay DGAC (75 mm)	radial dual[c]	40 kN, 105 psi	6.94 km/h (0.25)	50
507RF	Overlay DGAC (75 mm)	wide base single	40 kN, 110 psi	7.69 km/h (0.35)	50
508RF	Overlay ARHM-GG thick (60 mm)	wide base single	40 kN, 110 psi	[e]	50
509RF	Overlay ARHM-GG thick (60 mm)	radial dual	40 kN, 105 psi	e	50
510RF	Overlay ARHM-GG thin (37 mm)	radial dual	40 kN, 105 psi	e	50
511RF	Overlay ARHM-GG thin (37 mm)	wide base single	40 kN, 110 psi	e	50
512RF	Overlay DGAC (75 mm)	wide base single	40 kN, 110 psi	e	40
513RF	Overlay DGAC (75 mm)	aircraft wheel[d]	100 kN, 150 psi	e	50

[a] **Wide base single:** 425/65R22.5, tread 5 plies steel cord, sidewalls 1 ply steel cord, maximum load 10,500 lbs. at 110 psi cold

[b] **Bias-ply dual:** 10.00x20 in., tread 6 plies nylon cord, sidewalls 6 plies nylon cord, maximum dual load 6,300 lbs. at 90 psi cold

[c] **Radial-ply dual**: 11R22.5, tread 6 plies steel cord, sidewalls 1 plies steel cord, maximum dual load 5,750 lbs. at 105 psi cold

[d] **Aircraft wheel:** 46x15, reinforced tread, tubeless, 44,800 lbs. at rated pressure

[e] The wheel speeds were relatively constant for the three wheel types so they were not measured in subsequent tests.

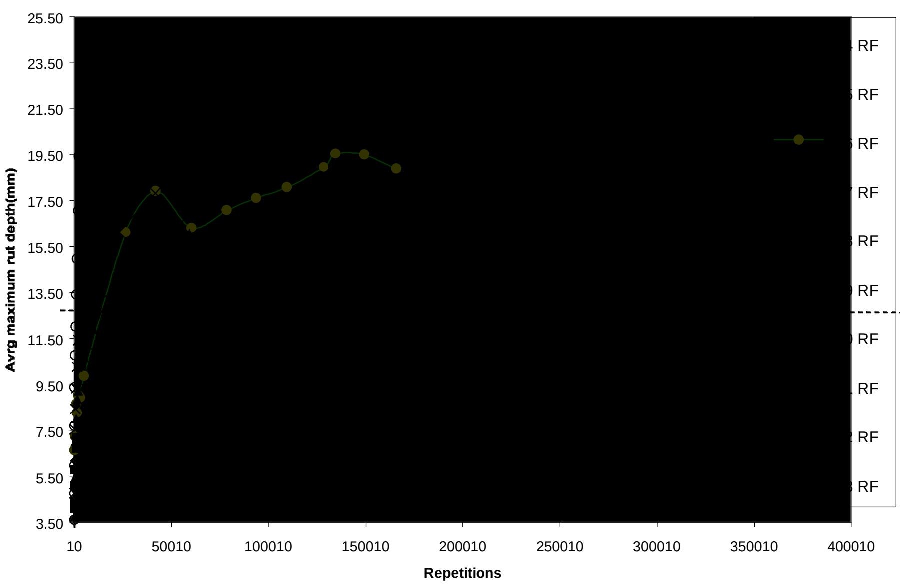


Figure 4. Plot of average maximum rut depth versus load repetitions for all test sections

Figure 4 illustrates the development of rut depth with load applications for all of the tests conducted. In this instance, the dual wheels with radial-ply tires result in somewhat more rutting than those with the bias-ply tires.[3] The wide-base single tire results in about a 25 percent increase

[3] The dual bias-ply tires operate at a somewhat lower tire pressure than the dual radial tires [620 kPa (90 psi) vs. 720 kPa (105 psi)]. It is likely that the comparative results of the two tire types could differ more than obtained here since the radial tires tend to "track" more than the bias-ply tires under normal operating conditions.

in rutting over the dual configuration, and the aircraft wheel causes significantly more rutting than the other tires. The data also demonstrate the significant influence of pavement temperature on the development of permanent deformation, i.e., comparison of the test results for the wide-base single tire at 40°C and 50°C (104°F and 122°F). These tests were completed in a relatively short time period. They demonstrate the usefulness of the HVS test to quickly evaluate performance in asphalt pavements. Thus the HVS can serve as a valuable validation technique for evaluation of improved mix analysis and design methods to mitigate rutting and as a rapid means to evaluate the influences of new tire types and gear configurations on mix rutting.

SIMPLE SHEAR TEST

The simple shear test, developed during the asphalt research program of the Strategic Highway Research Program (SHRP) (*7*), has been used to evaluate the rutting characteristics of mixes subjected to highway and aircraft loading conditions in both accelerated pavement tests and in-service pavements. For these evaluations, tests have been performed in repeated loading using a repeated shear stress pulse while the height of the specimen is maintained constant throughout the test (termed RSST-CH). Shear and vertical loads are applied by servo-hydraulic actuators which are computer controlled. For the test results reported herein, specimen size was 50 mm (6 in.) in diameter by 50 mm (2 in.) high.[4]

The RSST-CH results reported herein were obtained using a shear stress of 10 psi (69 kPa). Shear loading was applied in the form of haversine with a time of loading of 0.1 sec. and a time interval between load applications of 0.6 sec. This combination of stress level and time of loading was selected based on experience gained in mix analysis and design studies for highway loading conditions. Performance for a range in traffic loading has shown these test conditions to be reasonable (*7*). The tests are conducted to at least 5,000 stress repetitions or to a permanent shear strain of 5 percent, whichever occurs first.

Figure 5 illustrates an example of the relationship between permanent shear strain, ?^{p}, and stress repetitions, *N*, obtained in this test. Each curve is adjusted by defining the intercept of g^p at $N = 0$ based on the first 10 repetitions and subtracting this value from all measurements of g^p. An equation of the form:

$$g^p = aN^b \tag{1}$$

is then fit to the data for the values of N greater than 100 or 1000 repetitions depending on mix behavior. In this expression, the coefficients *a* and *b* result from the regression analysis. A shear modulus is also determined from the recoverable shear strain measured at $N = 100$ repetitions; i.e.,

$$G = \frac{t}{g_{recov.}} = \frac{shear\ stress\left[69kPa\left(10\,psi\right)\right]}{recoverable\ shear\ strain\ at\ N = 100} \tag{2}$$

For a given mix, the number of repetitions to 5 percent permanent shear strain is a function of its air-void content, increasing as the air-void content is decreased to a value between 3 and 2 percent. Below an air-void content of about 2 percent, with further decrease in air-void content, the number of repetitions again decreases.

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[4] The 6-in. diameter by 2-in. high specimen is normally used for mixes containing ¾-in. maximum size aggregate. If a larger maximum aggregate size is used, a larger specimen size is required (e.g. 8 in. by 3 in.). In addition to circular specimens obtained by coring, it is also possible to utilize rectangular specimens obtained by sawing from slabs.

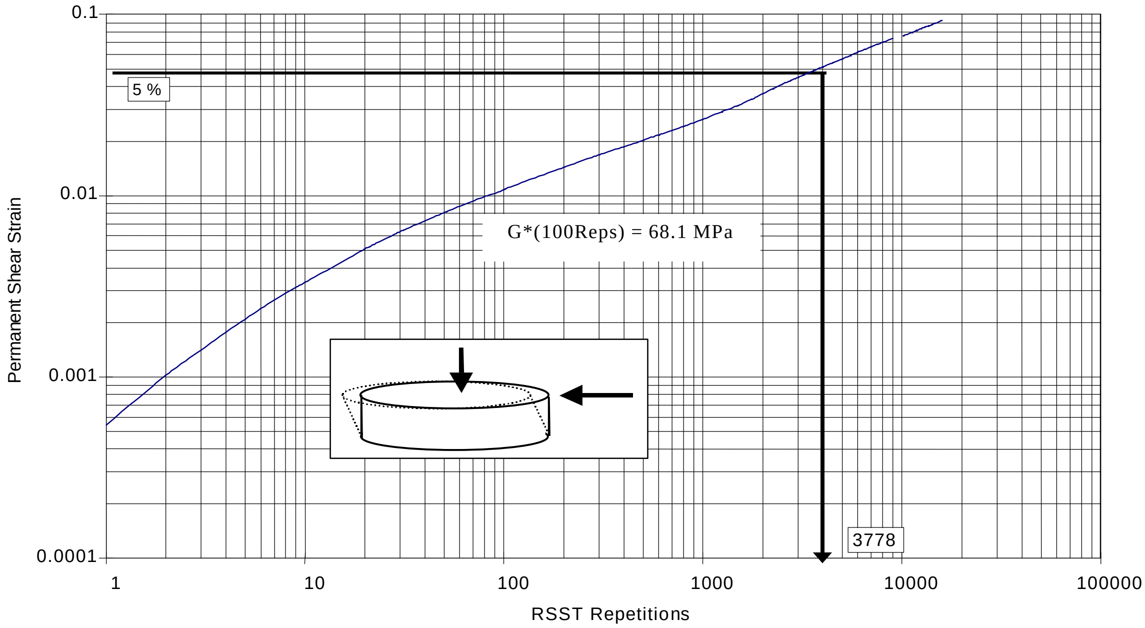

Figure 5. Shear strain, γ^p versus load repetitions, N.

For mix design using conventional binders, it is suggested that the test be performed at a single temperature, representative of the critical temperature at the pavement site.(*8*) The critical temperature is defined as the temperature at a 50 mm (2 in.) depth at which the maximum permanent deformation occurs, assuming in this case that the truck traffic is applied at a uniform rate throughout the year.

RSST-CH TEST RESULTS

Since its development in 1991 the RSST-CH (*14*) has been used in a number of applications involving both mix design and analysis of pavement performance (e.g., *6*, *9*, *10*, *12*). Results of these studies suggest the following:

1) The test should be performed on specimens prepared by rolling wheel compaction in the laboratory or on specimens obtained from in-situ pavements. Data illustrating this point are shown in Figure 6 in which the performance in the RSST-CH for specimens of asphalt-rubber hot mix prepared by rolling wheel compaction and the SHRP gyratory compactor are compared with the same mix obtained from pavement cores (*6*). It will be noted that the specimens prepared by rolling wheel compaction in the laboratory and by field compaction exhibit the same response characteristics at the elevated temperatures of 50°C and 60°C while the SHRP gyratory compaction produces specimens which are considerably stiffer. Results in Reference (*11*) support this observation as well.

2) The test can be used both for mix design and for rut depth prediction (*9*, *12*, *16*). Results presented in Figure 7 indicate the use of the RSST-CH for mix design purposes based on the procedure described in Reference (*7*). In this example mix designs were prepared for mixes

containing a PBB-6a* (PG64-40) binder and an AR-8000 (PG64-16) asphalt cement. In both cases a design binder content of 4.7 percent (by weight of aggregate) was recommended.

To evaluate the mix containing the PBA-6a* binder prior to its use in a long-life pavement on the I-710 Freeway in the Long Beach area, an overlay was constructed on an existing plain, jointed concrete pavement at the RFS. This overlay consisted of 75 mm (3 in.) of the mix with the PBA-6a* binder over 75 mm (3 in.) of the AR-8000 mix, both at 4.7 percent binder content (*9*).

Aggregate representative of the type likely to be used on the project was shipped from Southern California, mixed at a central batch plant, and placed by a local paving contractor. Both layers were compacted to about 6 percent air voids. Arrangements for this operation were made by the Asphalt Paving Association (of California) (APA) and the Northern California Asphalt Producers Association (NCAPA).

Following construction, a Heavy Vehicle Simulator (HVS) was used to load the PBA-6a* mix with about 10,000 unidirectional repetitions per day of a 40 kN (9,000 lb.) load on dual tires with a cold inflation tire pressure of 690 kPa (100 psi). The temperature of the pavement was maintained at the critical temperature, 50°C (122°F), at a 50 mm (2 in.) depth.

Results of accelerated loading on the PBA-6a mix carried to about 170,000 channelized repetitions is shown in Figure 8. Air void contents prior to trafficking were about 6 percent and reduced to about 3.5 percent after trafficking. Also shown in the figure are some of the results shown earlier in Figure 4. It is noted that the PBA-6a mix performed significantly better in terms of rutting than the other two mixes. For purposes of comparison, RSST-CH test results for the PBA-6a* mix are > 600,000 repetitions at an air void content in the range of 3-4 percent. For the other two mixes (DGAC and ARHM-GG) whose results are also shown in Figure 8, RSST-CH results are likely in the range of 10,000 to 100,000 repetitions for comparable air void contents.

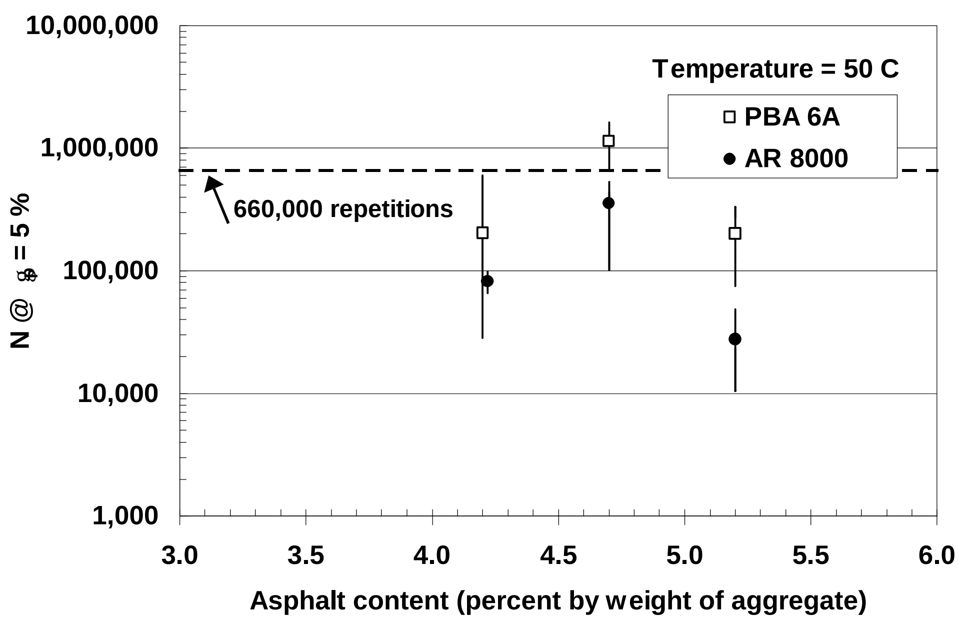

Figure 7. Repetitions to a permanent shear strain of 5 percent versus binder content; tests performed at 50°C (122°F)

The results of this study as well as other investigations suggest the RSST-CH provides a more suitable tool for the design of mixes containing modified binders than conventional tests such as the California Stabilometer. For the data shown in Figure 8 the stabilometer "S" value for the PBA-6a* mix was about 30 as compared to 43 for the AR-4000 mix (discussed earlier). Similarly the stabilometer "S" value for the AR-8000 mix, whose RSST-CH results are shown in Figure 7, was about 40.

The HVS test conducted on the PBA-6a* mix also provided the opportunity to evaluate an analytically-based procedure using results of the RSST-CH and layered-elastic analysis which had been developed to analyze pavement performance at WesTrack.(*12*)

In this approach [described in Reference (*12*)] the pavement is assumed to behave as a multilayer elastic system. Figure 9 illustrates the idealization used for the HVS test of the PBA-6a mix.

Based on the measured pavement temperature distribution during testing, the 150 mm (6 in.) asphalt-bound section was subdivided into three layers and stiffness moduli were assigned based on laboratory stiffness measurements obtained for both mixes. These values are shown in Figure 9 as well. The shear stress, τ, and elastic shear strain, γ^e, were determined using the multilayer elastic program ELSYM5 and values of τ = 120 kPa (17.4 psi) and γ^e = 0.00349 were determined.

Using the results of the RSST-CH tests and experience obtained in the analysis of WesTrack data, two equations corresponding to those developed in Reference (*12*) were obtained as follows:

$$g^{i} = 2.190\exp(0.05t)\, g^{e} n^{0.124} \tag{3}$$

$$g^{i} = 2.114\exp(0.04t)\, g^{e} n^{0.124} \tag{4}$$

Rutting was determined according to the procedure described in Reference (*12*) and no estimate was made of the contribution of the underlying layers to rutting since the asphalt pavement was placed on the PCC layer as shown in Figure 9.

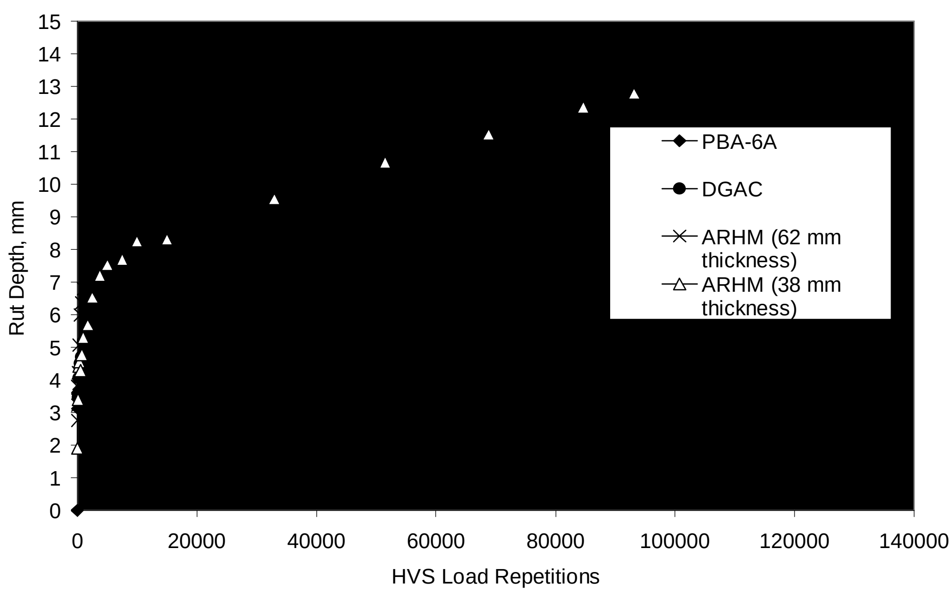

Figure 8. HVS rutting study results.

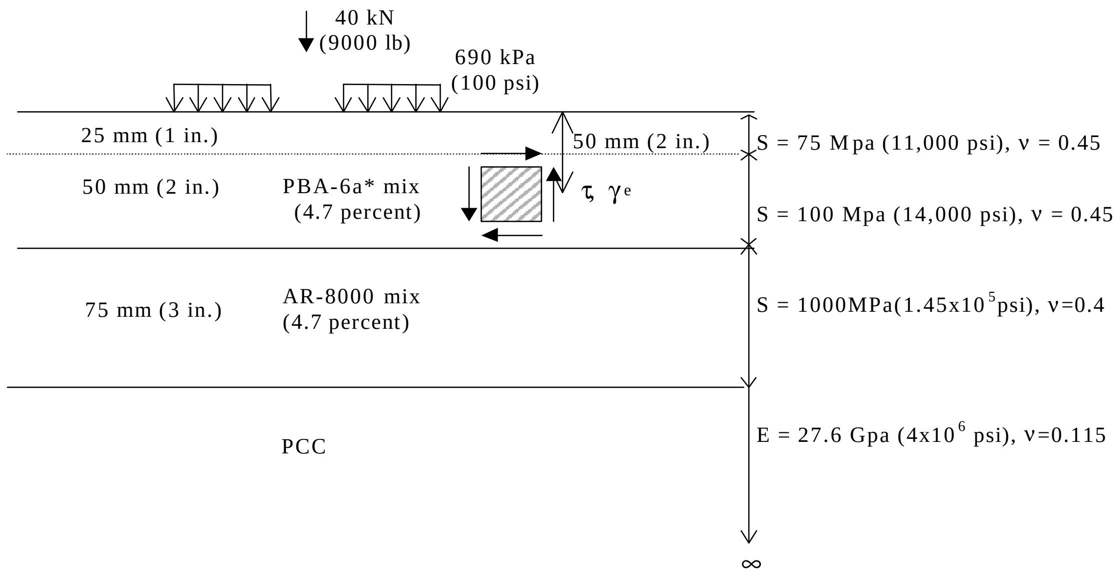

Figure 9. Test pavement cross-section for HVS test program.

Results of the computed values for rut depth according to Equations (3) and (4) versus HVS repetitions are also shown in Figure 10. The comparisons would appear to be reasonable, reinforcing the results obtained from WesTrack (*12*).

These investigations, which include both laboratory and accelerated field testing as well as analysis of representative pavement structures provide the basis for a procedure for mix design not only for highway pavements but airfield pavements as well. Such an approach is described in the next section.

USE OF RSST-CH FOR ESTABLISHMENT OF MIX DESIGN CRITERIA FOR TAXIWAY SUBJECTED TO HEAVY AIRCRAFT LOADING

In August 1995, shoving and rutting were observed in the asphalt-concrete turn areas of the taxiway adjacent and leading to the International Terminal of the San Francisco International Airport (SFIA). The distress occurred when the air temperature was about 35°C (95°F) and was attributed to slow-moving and sharp-turning Boeing 747-400 aircraft. Because the wing gear of this aircraft do not turn, a significant shear force, an action termed *sluing*, is exerted by each of the tires at the pavement surface. In October 1995, rutting distortions (termed *dimpling*) were observed under stop-and-go aircraft movements on another taxiway attributed primarily to the Boeing 747-400 in queue awaiting takeoff.

To correct these as well as other rutting problems resulting from the Boeing 747-400 operations, and enumerated in Table 2, a trial mix was selected to be used as a potential model for establishing a specification for a *High Stability* mix (*10*). It should be noted at the outset that the mixes which exhibited the rutting distress met current Federal Aviation Administration specifications (*13*).

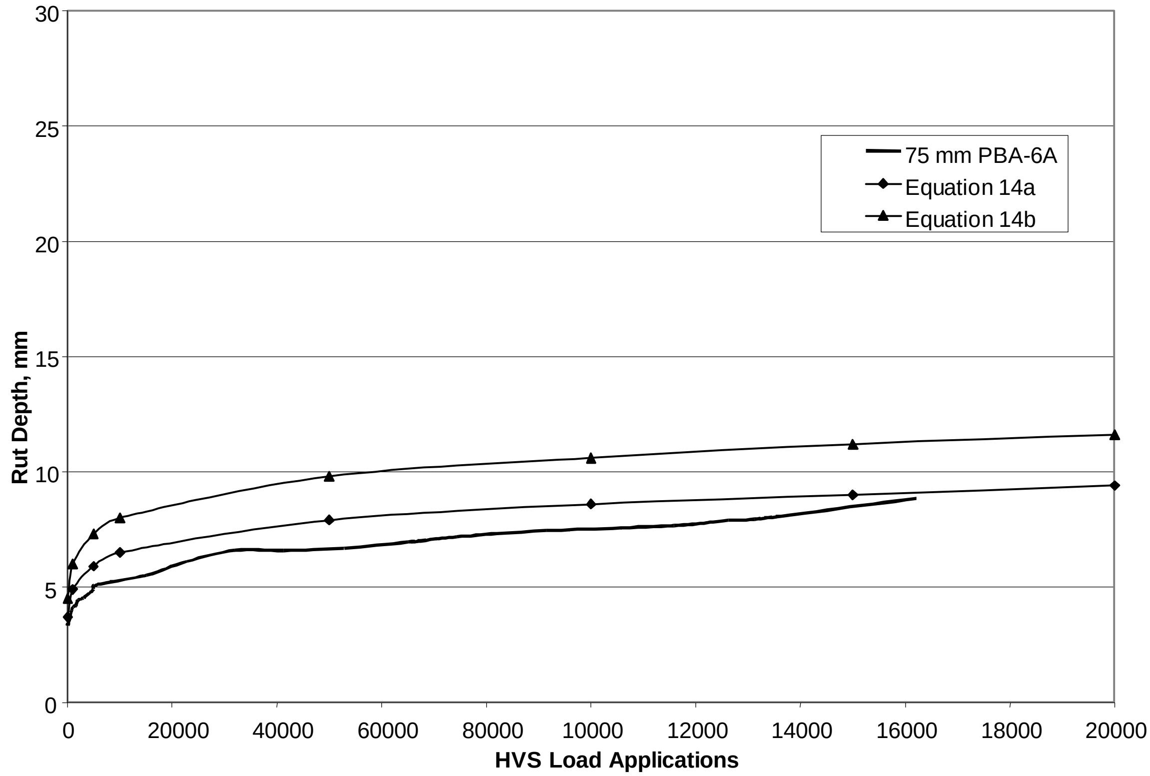

Figure 10. Rut depth versus unidirectional HVS load applications: pavement temperature at 50 mm (2 in.) depth = 50° C (122° F).

This sequence of events described in Table 2, including the introduction of the *High Stability* mix, provided an opportunity to evaluate the applicability of the RSST-CH for designing and evaluating asphalt (binder)-aggregate mixes for airfield pavements subjected to large, heavily loaded aircraft.

Materials used at the SFIA when the rutting failures occurred consisted of an AR-4000 asphalt cement and aggregate obtained from the nearby Brisbane quarry. The materials used for the *High Stability* mix consisted of an AR-16000 asphalt and an all-crushed granite aggregate from a quarry at Logan, California.

The RSST-CH was used to evaluate the permanent deformation characteristics of the cores obtained when the rehabilitation actions noted in Table 2 were taken. To evaluate field rutting performance of the *High Stability* mix placed on Taxiway B in August 1996, use was made of the laser profilometer, developed by the CSIR of South Africa and a part of the battery tests used to evaluate pavement response during HVS testing (*1*). Results of the RSST-CH are presented in Figures 11, 12, and 13. Figure 11 contains the data for the *High Stability* mixes from Taxiways A and B while Figure 12 contains the data for mixes containing the AR-4000 asphalt cement from Taxiways A, B, and M. Table 2 also indicates the approximate times at which the cores were obtained for shear testing.

As noted earlier, for a given mix, the number of repetitions to 5 percent permanent shear strain is a function of its air-void content, increasing as the air-void content is decreased to a value between 3 and 2 percent. Below an air-void content of about 2 percent, the number of repetitions again decreases (*7*).

Table 2. Sequence of distress development and associated rehabilitation measures at SFIA

Location	Date	Problem	Remedial Treatment
Taxiway A	August 1995	Shoving and rutting from turning B747-400 aircraft	Increase aggregate size to 1-in. maximum and change asphalt grade to AR-8000 asphalt cement
Taxiway B1	October 1995	Severe rutting (dimpling) caused by stop-and-go movements of B747-400	Increase aggregate size to 1-in. maximum and change asphalt grade to AR-8000 asphalt cement
Taxiway B	June 1996	Severe rutting and shoving caused by stop-and-go movements of B747-400	Introduction of *High Stability* mix with AR-16000 asphalt
Taxiway B1	June/July 1996	Severe rutting and shoving caused by stop-and-go movements of B747-400	Place *High Stability* mix
Taxiway B	August/ September 1996	Localized slippage failures due to lack of bond between lifts caused by dust in surface of first lift	Replace mix in slippage[1] areas with same *High Stability* mix; place and compact mix in one 4-in. thickness
Taxiway M	January 1997	Severe rutting and shoving caused by stop-and-go movements of B747-400	Place *High Stability* mix
Taxiway A	January 1997	Rutting and shoving in mix with AR-8000 and 1-in. maximum size aggregate	Place *High Stability* mix

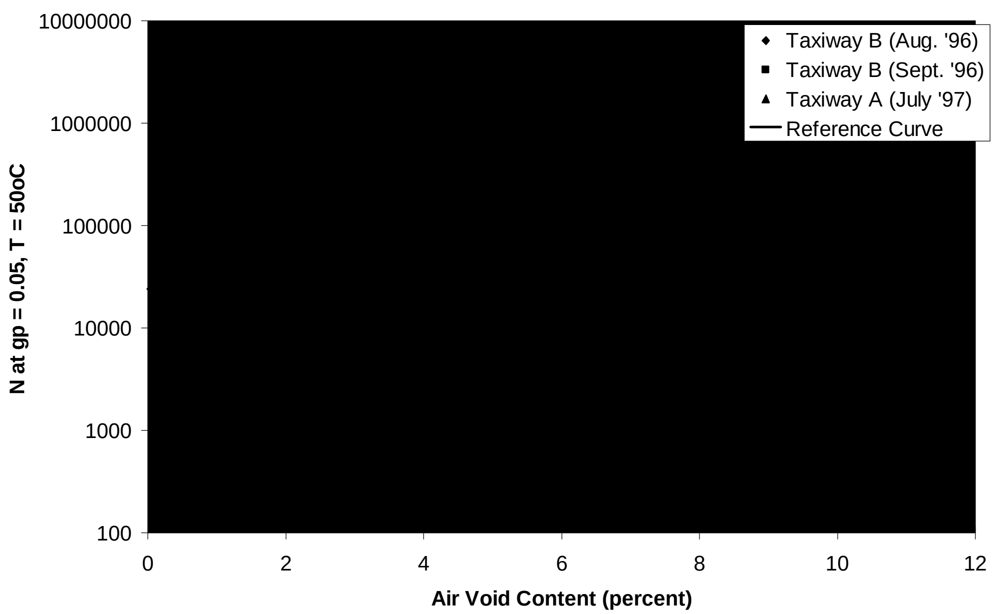

Figure 11. Shear Stress Repititions to 5 percent shear versus air-void content at 50°C—High Stability Mixes.

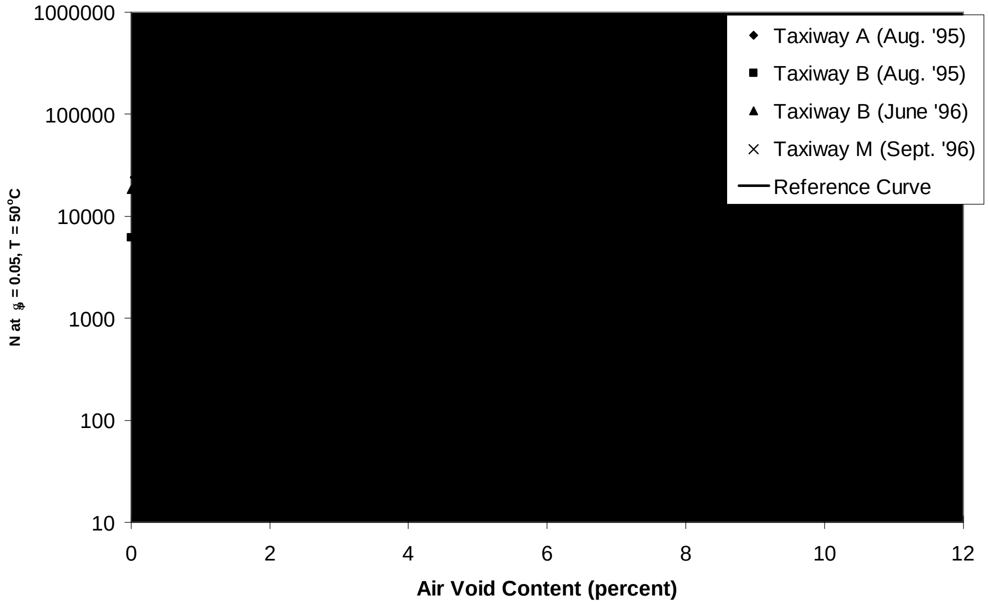

Figure 12. Shear stress repetition to 5 percent shear strain versus air void content at 50°C—mixes containing AR-4000 asphalt cement

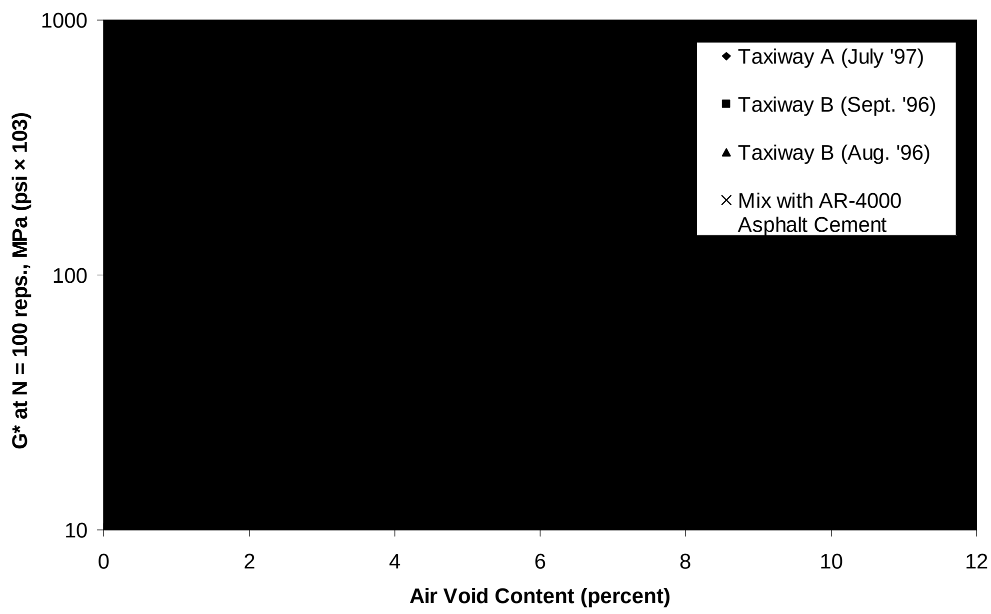

Figure 13. Mix stiffness measured in shear versus air void content

In Figure 11, a line has been drawn and designated as a "reference curve" in order to delineate the area above which the results of the shear test data on the *High Stability* mix are generally situated (24 of 28 data points). When this line is placed on Figure 12, it will be noted that with few exceptions, the mixes that have exhibited rutting and shoving fall below the line (21 of 27 data points).

An additional concern is whether one can differentiate between the mixes based on stiffness (in this case, shear stiffness) as measured in the simple shear equipment. To answer this concern, the available stiffness data for the various mixes are plotted in Figure 13. Note that there is no differentiation between the mixes containing the AR-4000 asphalt with Brisbane aggregate and the mixes containing the AR-16000 material with Logan granite. These findings underscore the need to perform a repeated load test to evaluate permanent deformation resistance of mixes.

A laser profilometer, Figure 14, was used to measure transverse profiles across Taxiway B at points established by precise surveys with respect to horizontal location and elevation. At each of the stations, locations for the profilometer supports were marked so that subsequent measurements could be made at exactly the same locations. Measurements were taken at three stations along the taxiway at 3-month intervals up to about 15 months after placement of the *High Stability* mix (November 1997) for a total of six measurements.

The laser profilometer spans a distance of 3 m (9.8 ft.); accordingly, it was necessary to move the equipment transversely to cover the 25-m (75-ft.) width of the taxiway. To generate the surface profile, the distance between the laser and pavement surface was measured every 9 mm across the taxiway, excluding the shoulders.

An example of a surface profile is shown in Figure 15. The variability shown in Figure 15 is due to the sensitivity of the profilometer laser to the microstructure of the pavement surface and the 9-mm distance between measurements. No rutting is evident from the measurements. However, it would appear that settlement of 30-40 mm has occurred on Taxiway B during the 15-month monitoring period.[5] Data presented in Figures 11 and 12 serve as the basis for new mix design criteria. One approach is to use the "reference curve" as the basis for mix evaluation. Although the criteria were developed from the available mixes, the results are applicable to similar mixes and environmental conditions as those found at SFIA. The criteria can be validated and modified with data for additional mixes. If a specimen is compacted to an air-void content of about 3 percent and it provides a value of N = 25,000 repetitions at 5 percent strain in the RSST-CH, it should be capable of sustaining traffic of the type described herein since this requirement represents the behavior of the *High Stability* mix used at SFIA.

Figure 14. Laser Profilometer

[5] Permanent deformation of the type experienced at SFIA; i.e., rutting, dimpling, and shoving.

While the "reference curve" of Figures 11 and 12 was established initially by engineering judgement, a subsequent analysis using a logistic regression model was performed to analyze improved criteria. The results are shown in Figure 16. In this regression, the probability of failure is given in Equation (5). Failure is defined as the mix not being able to withstand the traffic.

$$\text{Probability of Failure } = \frac{1}{1 + \exp(-11.8119 + 0.6002 \cdot AV + 0.9995 \cdot \ln N)} \tag{5}$$

where AV = percent air-void content, and
N = repetitions to 5 percent shear strain.

Figure 16 shows isolines of probability of failure corresponding to values of 20, 40, 60, and 80 percent. The reference curve of Figures 11 and 12 corresponds to a probability of failure of 50

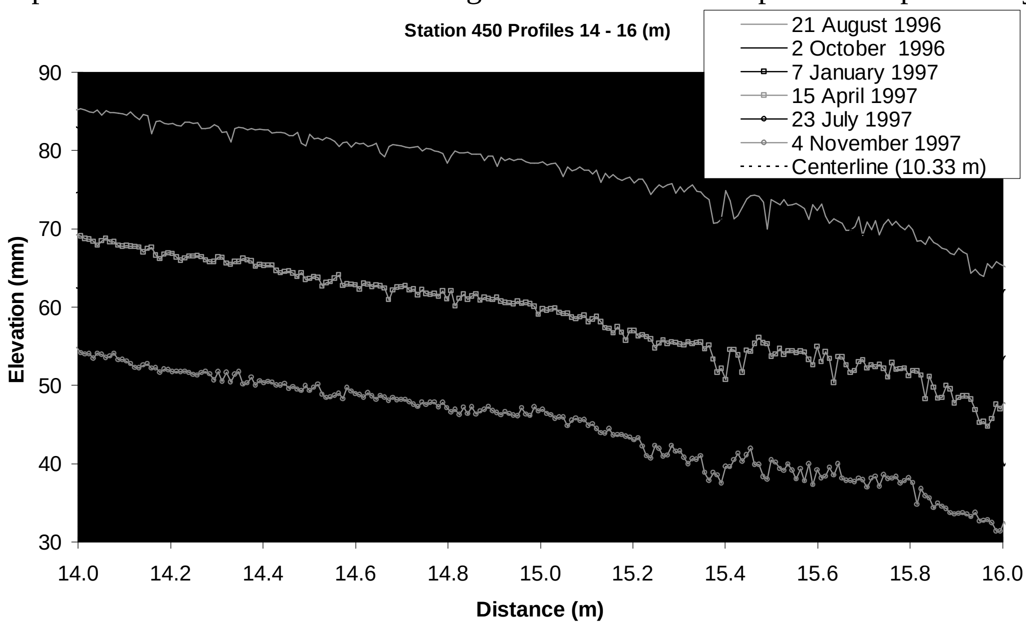

Figure 15. Taxiway B profile data, Station 450, 12–14 m.

percent. Thus, based on Figure 16, tentative criteria for mix design using the shear test (RSST-CH) can be established for different probabilities of rutting failure. Allowable repetitions to failure in the RSST-CH at 50°C for the conditions of loading described herein for probabilities of failure of 20 to 50 percent, at an air-void content of 3 percent are as follows:

Probability of Failure	N_P at γ^p = 5 percent
50	25,000
40	35,000
20	100,000

This information can be used as described in Reference (*7*) for mix design purposes.

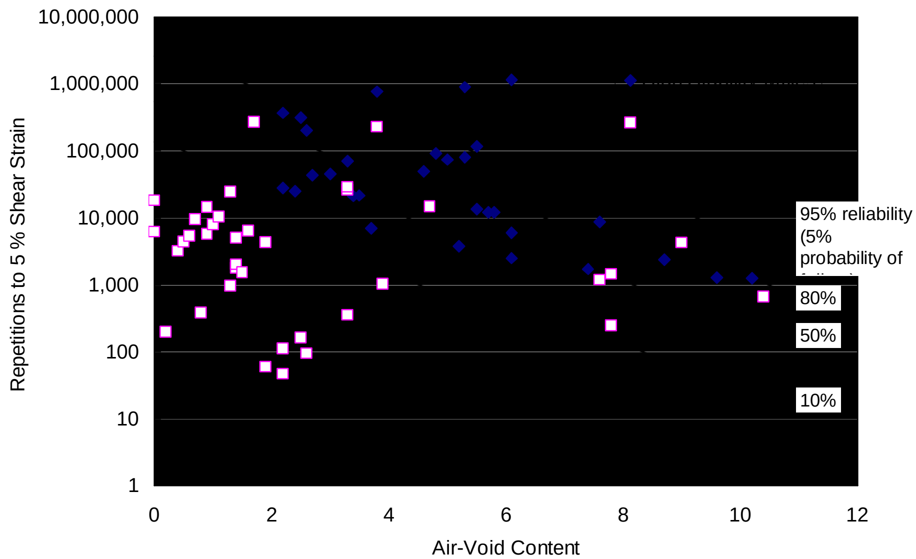

Figure 16. Shear stress repetitions to 5% shear strain versus air-void content at 50°C – all mixes.

SUMMARY

This paper has addressed one aspect of the performance of asphalt concrete pavements, rutting of the asphalt mix under high temperature loading conditions. It illustrates how accelerated pavement testing, in this case using the HVS, can be combined with a laboratory performance test, the RSST-CH, and analytically-based analyses to address mix analysis and design issues for both highway and airfield pavements.

While the mix design procedure using the Hveem Stabilometer has provided rut resistant pavements for many years using conventional asphalt binders, it does not appear to adequately measure the performance of mixes containing modified binders. This has been demonstrated herein for a mix containing a modified binder as compared to mixes containing conventional asphalt cements, even though their design stabilometer “S” values were significantly different.

The data presented herein illustrate how new test methodology, like that developed during the SHRP program, can be relatively quickly evaluated to provide confidence in its use for the design of mixes containing other than conventional asphalt binders.

Results of the tests corroborate other findings; for example, in mix testing for permanent deformation it is important to prepare specimens using procedures that produce similar aggregate structures to those obtained during actual construction. Rolling wheel compaction of the type used herein appears to meet this criterion.

A mechanistic empirical approach to estimate rut development with traffic which had been developed as a part of the WesTrack full-scale accelerated pavement test was evaluated using HVS loading under controlled temperature conditions. While the results were limited to one high temperature test with the PBA-6a* mix, they suggest that this methodology may provide a suitable procedure for use as a part of mix design methodology for heavy-duty pavements. The results demonstrate the importance of blending analyses, laboratory testing, and full-scale accelerated paving testing to achieve a credible pavement engineering solution.

While not directly applied to aircraft loading in the HVS, RSST-CH test data for in-situ cores from the SFIA coupled with field transverse profile measurements with the HVS test program developed laser profilometer illustrate an approach which can be used to develop mix design criteria for specific aircraft loading and environmental conditions. Presumably the credibility of this approach is enhanced by the body of evidence preceding it.

Finally, the results presented herein illustrate how HVS testing can be used to directly investigate comparative performance, of different tire types in this instance, to achieve information which is immediately useful to the pavement engineering community. Other examples might include aspects of QC/QA specifications and new materials and pavement structures.

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